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Nikola Tesla: Electrifying Legacy

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Introduction

NIKOLA Tesla was one of the most accomplished inventor-scientists of the late nineteenth and early twentieth centuries. He invented radio and created the polyphase alternating current system of motors and generators that powers the world. Without his inventions the widespread electrification that greatly contributed to technological advancement of the twentieth century would not have been possible. Tesla was also a visionary genius, who conceived many ideas, some controversial at his time, that established the basis for everything that now powers our world with energy and information, including several of today's mainstream technologies ranging from wireless communication systems, radar, television broadcasting, robotics, computers, faxes, and even the U.S. Strategic Defense Initiative.

In writings about Tesla, one often finds statements such as that he "invented the twentieth century" or "the twenty first century", or even that he "invented the future".

Among the more than 700 of Tesla's other inventions/patents are the rotating magnetic field principle, polyphase alternating-current system, induction motor, wireless communication, fluorescent lights, use of high-frequency currents in medicine and remote control.

It is interesting to point out that the U.S. National Academy of Engineering (NAE) chose "Electrification" as the greatest engineering achievements of the twentieth century [1]. Here is the top 20 technological achievements listed by NAE:

1.Electrification, 2.Automobiles, 3.Airplanes, 4.Waters supply and distribution, 5.Electronics, 6.Radio and Television, 7.Agricultural Mechanization, 8.Computers, 9.Telephone, 10.Air Conditioning and Refrigeration, 11.Highways, 12.Spacecraft, 13.Internet, 14.Imaging, 15.Household Appliances, 16.Health Technologies, 17.Petrochemical Technologies, 18.Laser and Fiber Optics, 19.Nuclear Technology, 20.High-Performance Materials.

The list was announced during the National Engineering Week by astronaut/engineer Neil Armstrong on behalf of NAE at a National Press Club luncheon in February, 2000. In his presentation Neil Armstrong, the first man on the Moon, said jokingly that his astronomic feat did not even rank among the top 10 engineering achievements. In fact, space exploration came 12th, right before the Internet and right after highways.

Widespread electrification was chosen based on the key criterion of improving the quality of life for the most people – and the conclusion that nothing else on the list would have been possible without the widespread electrification! The explanation that appears on the NAE Web presentation still does not give full credit to Nikola Tesla for his contributions to the widespread electrification of the World!

Nikola Tesla was born at midnight between July 9 and 10, 1856, to a Serbian family in Smiljan, Lika, then part of the Austria/Hungarian Empire. He was the second son of Djuka (Georgina) Mandic and the Reverend Milutin Tesla, who was well educated and highly respected Serbian Orhodox priest. He came to the USA in 1884 to work for Thomas Edison. In 1891 he became a U.S. citizen. After his demonstration of wireless communication in 1893 and after being the victor in the "War of Currents" against Edison's DC system, he was widely respected as America's greatest electrical engineer. With no skills at handling his finances, Tesla died impoverished and forgotten at the age of 86, but his inventions changed the world.

Short review of major Tesla's inventions

At the end of the 19th Century, electric power was at its beginning but growing rapidly. The first commercial power plants used direct current (**DC**) for incandescent lighting and power starting in 1882. However, the **DC** power could only be distributed over a limited area around the generating station (less than a mile). It was the work of **Nikola Tesla** that led to the broad commercialization of **alternating current (AC) system,** which enabled transmission of high-voltage power over large distances. B. A. Behrend, engineer and colleague of Tesla, said in 1917 *"Were we to seize and eliminate from our industrial world the results of Mr. Tesla's work, the wheels of industry would cease to turn, our electric cars and trains would stop, our towns would be dark, our mills would be dead and idle. Yes, so far reaching is his work that it has become the warp and woof of industry. The name of Tesla ... marks and epoch in the advance of electrical science. From that work has sprung a revolutions."* [2]

The Discovery of the Rotating Magnetic Field and AC System of Motors, Generators and Transformers. [2-5,7]

Tesla's discovery of the rotating magnetic field produced by the interactions of two and three phase alternating currents in a motor winding was one of his most significant achievements, and formed the basis of his induction motor and polyphase system for the generation and transmission of electricity. Thanks to this invention, large amounts of electrical power could be generated and transmitted efficiently over long distances.

When Tesla came to the USA, he had already developed in his mind many ideas that would soon materialize into the AC system of motors, generators and transformers. In "My Inventions", Tesla explains how he got the idea about rotating magnetic field while walking with a friend in Budapest:

"*One afternoon I was enjoying a walk with my friend in the*

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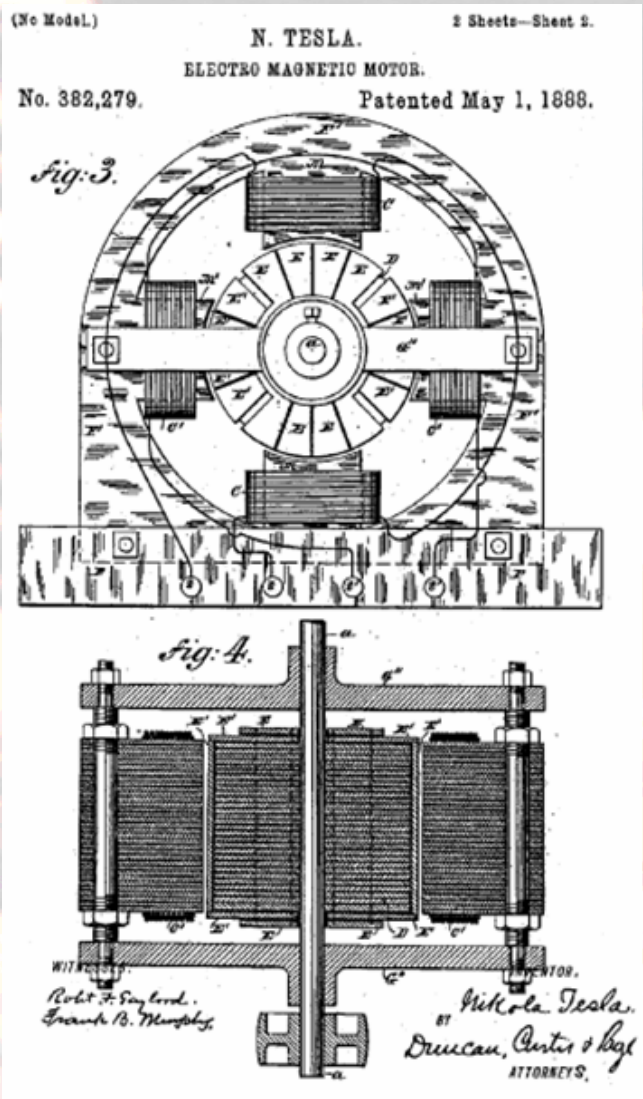
city park and reciting poetry - Goethe's Faust. The sun was just setting. The idea came like a flash of lightning and in an instant the truth was revealed! I drew with a stick on the sand the diagram, and told my friend - See my motor here; watch me reverse it!"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N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 382,279. Patented May 1, 1888.

fig: 3.

fig: 4.

Nikola Tesla.

BY

Duncan, Curtis & Page

ATTORNEYS.

Figure 1. One of Tesla's patents on motors

However, during his brief work for Edison in 1884, Tesla was not able to convince Edison to replace DC with AC system, and left to establish his own companies, first the Tesla Arc Light Company in 1885, and the Tesla Electric Light Company in April 1887 at Rahway, New Jersey. By December of 1887, Tesla filed for seven U.S. patents that fully described the AC system of generators, motors, transformers, transmission lines and lighting. Figure 1 shows one of the electro-magnetic motors for which Tesla received patent in 1888. Fig.2 shows a two-phase induction motor that Tesla demonstrated during his first major lecture before the American Institute of Electrical Engineers (which later become IEEE) at Columbia University on May 16, 1888. The title of this historicla lecture was: "*A NEW SYSTEM OF ALTERNATING CURENT MOTORS AND TRANSFORMERS"*

In May 1888, George Westinghouse, the head of the Westinghouse Electric Company in Pittsburgh, bought the patent rights to Tesla's polyphase system of alternating-current (AC) dynamos, transformers, and motors, for $25,000 in cash, $50,000 in notes and a royalty of $2.50 per horsepower for each motor.

Agreement meant that Westinghouse would pay Tesla, and his partners (Peck and Brown) $315,000 over the 17 year life of the patents. Westinghouse hired Tesla and brought him to Pittsburgh. The chief engineer in the Westinghouse Electric Company did not know how the Tesla motor operated, but he the motor worked when he made it. In addition, Westinghouse engineers preferred 133 cycles per second, but Tesla insisted on SIXTY CYCLES per second that is still used today in the US.

This transaction started a power struggle between Edison's direct-current systems and the Tesla-Westinghouse alternating-current approach, which Tesla-Westinghouse eventually won out. At approximately the same time, financier J.P. Morgan took over the Edison Company and several other companies to form the new General Electric (GE) Company. Both companies bid to power and illuminate the Chicago World's fair, to become the first fully electrically illuminated fair in World's history. GE wanted to utilize the DC system while Tesla-Westinghouse bid to do it with a new AC system – for nearly half of what GE proposed.

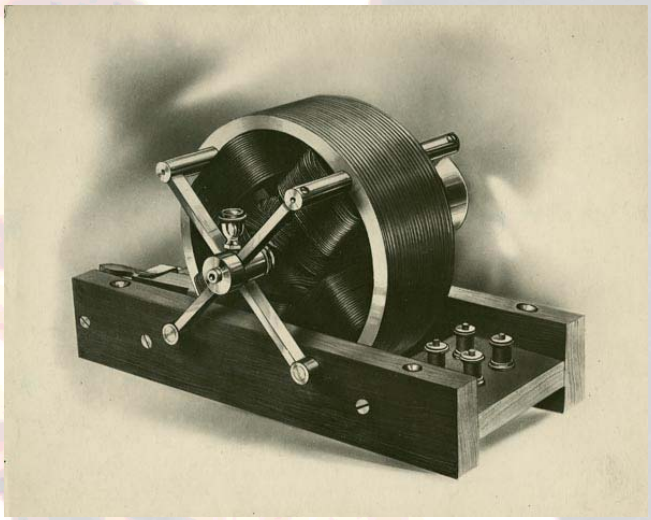


Figure 2. A two-phase induction motor that Tesla demonstrated at Columbia University in 1888

The Tesla-Westinghouse AC system won, and the Chicago World Fair opened on May 1, 1893, when the US president Grover Cleveland pushed a button and the "electric" future began in the most spectacular lighting display (Fig.3).

Figure 3. The Chicago World Fear opening on May 1, 1893

Tesla used this opportunity to demonstrate the principle of the rotating magnetic field by showing the "Egg of Columbus" (Fig.4) and the first neon lights (Fig.5). Tesla twisted the neon tubes to form the names of his favorite scientists (Faraday, Maxwell, Henry) and Zmaj, his favorite Serbian poet.

Figure 4. The "Egg of Columbus" Tesla used for demonstration of rotating magnetic field

Niagara Falls. Tesla's dream to harness the power of Niagara Falls (Fig.5) soon become reality. In October 1893 the Niagara Falls Commission awarded Westinghouse a contract to build the power plant at the Falls, using the generators that Tesla designed. Those were dynamos of 5000 horsepower - the largest ever built in the World at that time. General Electric, licensing certain number of Tesla's patents, was awarded a contract to build 22 miles of transmission lines to Buffalo, a city near the Niagara Falls.

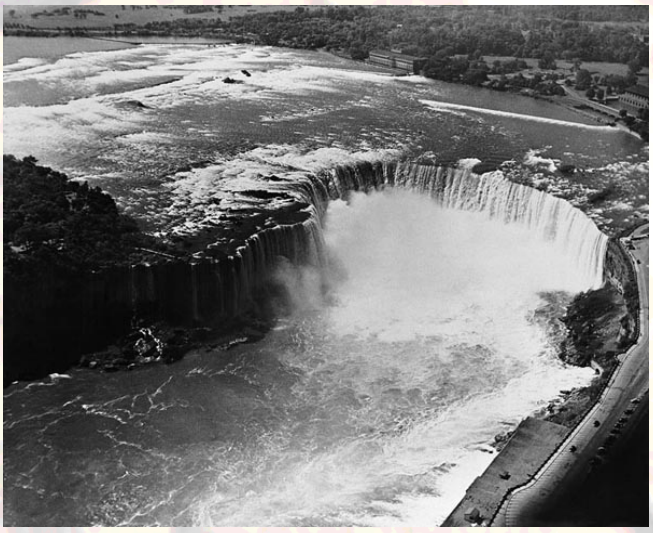


Figure 5. Niagara Falls

Tesla's polyphase system would be used throughout the entire project. The first three Niagara AC generators went on line November 16, 1896 (Fig.6). "*The evolution of electric power, from the discovery of Faradey in 1831 to the initial great installation of the Tesla polyphase system in 1896, is undoubtedly the most tremendous event in all engineering history*" (Charles E. Scott, 1943) [2]

Among 13 patents that were used by Westinghouse Company for the Niagara Falls Power Station, nine were Tesla's patents (Fig.7).

Figure 6. The first three AC generators went on line at the Niagara Falls Power Station in 1896

Figure 7. Nine of thirteen patents used at the Niagara Falls Power Station were Tesla's

To this day, the three-phase form of Tesla's polyphase system is used for the generation and transmission of electricity. Moreover, the conversion of electricity into mechanical power is made possible by updated versions of Tesla's three-phase and split phase motors. [2,3,4,9]

Thomas Alva Edison is a very familiar name in the US today and his name is linked to the electrification of the US, thanks to his great ability to promote himself, and the Edison Foundation that continues to promote Edison to this date. In reality, Edison did not create or develop the alternating current system. He fought its adoption bitterly, choosing instead to promote a system of direct current that had already been invented by others. It was Thomas Edison who invented the electric chair to frighten people away from the use of Tesla's AC system of electricity. In short, Edison's brief role in the electrical power industry was that of an entrepreneur who failed, rather than an inventor. It was Nikola Tesla's discovery of the rotating magnetic field principle in 1882 and patented in 1888 that gave us our modern-day system of electrical power distribution.

The Discovery of the Tesla Coil and Transformer – Experiments with High Frequency. [2-9]

Tesla's experiments with high frequency and high voltage alternating currents resulted in the development of the "*Tesla Coil*" which is still used as a major component in numerous electronic devices. "Tesla coil" is a transformer with an air core that has both its primary and secondary tuned in resonance. His first patent on Tesla Coil was in 1891 (No.454,622).

Figure 8. Tesla in his Colorado Spring Laboratory

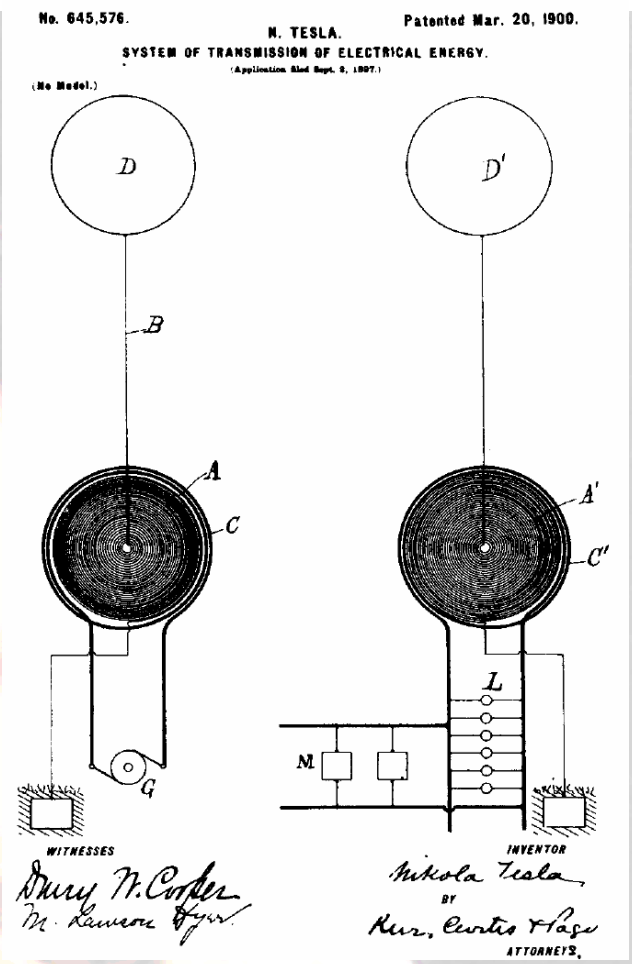


Figure 9. Tesla's basic radio patent No. 645,576 filed in 1897 and granted in 1900.

In 1899 he build his high-frequency laboratory in Colorado Springs (Fig.8), and in 1900 another laboratory in Long Island after his return to New York. In "*Nikola Tesla Colorado Spring Notes 1899-1900*" Professor Alaksandar Marincic writes:

"In 1898, Tesla's creativity in the field of high frequencies were at its peak. From his initial ideas in 1890 and his first pioneering steps, he had worked with such intensity that many of his inventions and discoveries, which he had given the world by this time, have reminded unsurpassed to this day… Always true to his principle that ideas must be experimentally verified, Tesla set about building powerful high-frequency generators and making experiments in wireless power transmission."

As part of other experiments Tesla also developed the precursors of modern neon and florescent lights. These elongated glass tubes filled with gas and coated with phosphor, were emitting light through excitation in his high voltage experiments. He also discovered that high voltage current could be made harmless by using alternating current scheme at very large frequencies and predicted that it could be used for medical purposes. He also experimented with X-rays from 1894 – 1896, basically before and after the Roentgen explained their nature and origin.

The Great Radio Controversy. [2-9]

Guglielmo Marconi was the first to send a message across the ocean and, and thus, he is partly responsible for 'developing' radio...but he did NOT invent it. Tesla did. Otis Pond, an engineer then working for Tesla, said, *"Looks as if Marconi got the jump on you."* Tesla replied, *"Marconi is a good fellow. Let him continue. He is using seventeen of my patents.*"

James Maxwell lay down the theoretical basis of electro-magnetism. Heinrich Hertz had tested Maxwell's theory and verified the existence of radio waves in his experiments from 1878-88. However, the apparatus used by Hertz and later by Marconi was not to be used in today's radios. Tesla filed his basic radio patent applications in 1897, and the patents were granted in 1900 (No.645,576 and No.649,621) – Fig.9.

Most people are unaware of what happened June 21, 1943: The United States Supreme Court made a landmark decision that essentially settled the long dispute between Marchese Guglielmo Marconi and Nikola Tesla. The court's decision, Case No. 369, identified as "Marconi Wireless Telegraph Company of America vs. United States," rendered invalid Marconi's basic patent No.763,772 dated June 28, 1904. Tesla's patent No. 645,576 of March 20, 1900, and its subdivision patent for apparatus No.649,621 dated May 15, 1900, had priority. Still, in a special journal issue, celebrating 100 years of radio, International Telecommunication Union did not mention Tesla among "the six great inventors of radio" (Faraday, Maxwell, Branly, Lodge, Popov, Marconi).

However, the 1909 Nobel prize in Physics was awarded jointly to: Marconi and Carl Ferdinand Braun in recognition of their contributions to the development of wireless telegraphy.

Remote Control and Automation. [2-10]

In 1898, at the first Electrical Exhibition in Madison Square Garden, Tesla demonstrated the world's first radio-controlled robot boat. Tesla applied his receivers and

transmitters in remote ship control, and he was granted a patent in 1898 for *"The Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles"*- Tesla's patent No.613,809 (Fig.10) of November 8, 1898. This invention made Tesla an originator of remote control. Unfortunately, as with many of Tesla's inventions, this invention was so far ahead of its time that those who observed it could not imagine its practical applications.

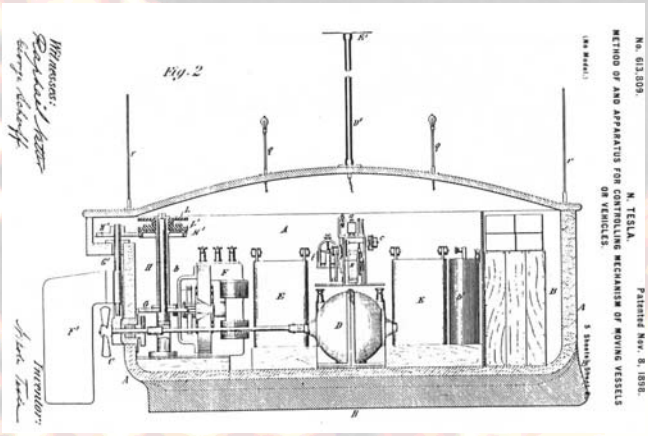


Figure 10. Tesla's U.S. patent No. 613,809 granted in 1898 describes the first remotely controlled device in the World.

The following excerpts from renown scientists criticizing Tesla's work show clearly that Tesla was so far ahead of his time, that he was mostly misunderstood and criticized:

Professor Cyrus Bracket of the Princeton University, in his interview for the "Electrician" in 1898: *"The shortest, most correct and most complete criticism which I can make reference to this bold boast is that what is new about it is useless, while that which is useful had all been discovered by other scientists long before Tesla made this startling announcement. There is nothing new about this. The theory is perfect, but the application is absurd."* 16

Tesla even contacted the U.S. Navy and offered his plan to construct a remotely controlled torpedo, but was rejected – the Navy did not have use for it!

Today, more than 100 years since Tesla remotely controlled his boat, we are witnessing widespread use of wireless remote control in household appliances (TV, VCR, CD, garage door openers, car locking system, toys), cordless phones, various medical applications, satellites, etc.

Tesla's visionary ideas

"The present is theirs; the future, for which I really worked, is mine." Tesla

In his visionary ideas Tesla was so far ahead of his time, so much a visionary, that his contemporary scientists really didn't understand what he was doing. We witness today realization of some of Tesla's visionary ideas, that he envisioned at the end of 19th and the beginning of 20th century. Many times he was misunderstood, or looked upon as an eccentric or even a lunatic. This created a great difficulty for Tesla and his ability to attract investors who would fund his research work. Only in few cases (such as collaboration with Westinghouse) he was able to fully complete his visions. In 1900, Tesla began construction on Long Island of a wireless world broadcasting tower (Wardenclyffe Tower), with $150,000 capital from the American financier J. Pierpont Morgan. Tesla was planning to provide worldwide communication with ability to send pictures, messages, weather warnings, and stock reports. The project was abandoned because of a financial panic, and J.P. Morgan's withdrawal of support.

Several Tesla's biographers point out that Tesla was a true scientist who lacked ability to broadly commercialize his work. Tesla needed money to do his research, while Edison used his inventions to earn a lot of money.

Among many Tesla's visionary ideas, we will mention only few that came to realization only recently, or are still waiting to be utilized: (a) Global wireless system for transmission of signals and energy, (b) Robotics and remote control foundations, (c) Vertical takeoff aircraft (VTOL), (d) Pump design suited for micromachines, (e) Use of geothermal energy, and (f) Vision of "electrical" future. [10]

Vision of Wireless Communication Magnifying Transmitter patented 1914 [2,3,5,10,13]

In early 1990's Tesla wrote *"…a telephone subscriber here may call up and talk to any other subscriber on the Globe. An inexpensive receiver, no bigger than a watch, will enable him to listen anywhere, on land or sea, to a speech delivered, or music played in some other place, however distant."* Sounds familiar? It took a better part of the 20th century for this Tesla vision to be realized. He had three goals: to develop a transmitter of great power, to perfect means for individualizing and isolating the energy transmitted (e.g., signals), to establish the laws of propagation of currents through the earth and the atmosphere. [10]

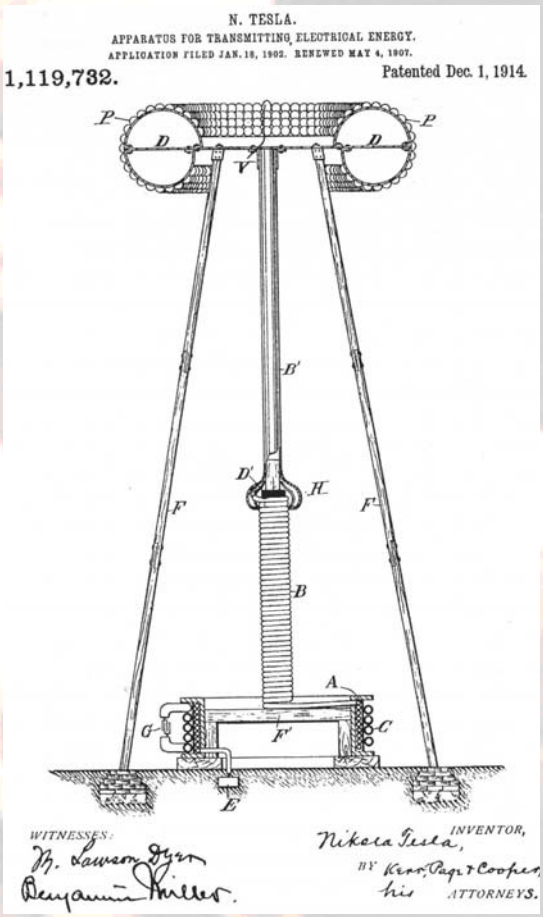


Figure 11. Tesla's Magnifying Transmitter Patent

Tesla envisioned global system of multimedia communication included: world-wide wireless transmission of signals, pictures, and messages; integration with existing communication equipment; the universal distribution of general news, by telegraph or telephone, in connection with

the Press (Internet); the interconnection of the existing telegraph/telephone exchanges or offices in the world; the interconnection and operation of all stock tickers of the world; global weather warning; the establishment of intelligence transmission for exclusive private use; the establishment of secret and secure government telegraph service; the global positioning system.

He also talked about using the same system to transmit energy, and submitted patent application in 1902 for "Apparatus for Transmission of Electrical Energy", that was granted in 1914. Initially, J.P. Morgan agreed to give Tesla $150,000 to built his first magnifying transmitter, and by 1901 the Wardenclyffe project was under construction.

However, with Markoni making progress in signal transmission, and Tesla wanting to provide free energy to the World, J. P. Morgan cut funding for the project, and in 1917 the tower was raized.

Robotics and remote control foundations (Patented in 1898). Tesla laid the foundation of remote control systems (what he called teleautomation) in 1898 at the first Electrical Exhibition in Madison Square Garden. He demonstrated how the ships and mechanical gadgets could be controlled remotely using a wireless principle.

In Tesla's own words we can recognize the basis for what we call today "Computers" and even one step further "Artificial Intelligence": *"[it will be able to follow a course laid out …or obey commands given far in advance, it will be capable between what it ought and what it ought not to do … and of recording impressions which will definitely affect its subsequent actions*".

Vertical takeoff aircraft -VTOL (Patented in 1928). [5,10] The initial idea appears in 1921. He envisioned a vertical take-off and landing aircraft, with combined helicopter and airplane features. Although he gave a thrust analysis of VTOL, it was never built by Tesla. However, VTOLs are in military use today (V-22 Osprey, for example). Tesla also envisioned a horseshoe-shaped VTOL with a horizontally placed turbine, which rides on a thin layer of air. Tesla never built it, but similarly designed hovercraft is commercially available today. (Fig.12)

Pump design suited for micromachines (Patented in 1920). Traditional method of controlling fluid flow with valves is imperfect due to: mechanical wear of moving parts, inability to control rapid flow "impulses", inability to control the flow when the fluid is highly heated or corrosive. Tesla proposed an ingenious conduit without moving parts, that could be defined as a "fluid diode". It has clearly defined "direct vs. reverse" flows, such that the resistance in the reverse flow is several hundred times larger than in the direct flow. It could be easily constructed and modularly expanded. It is ideally suited for micromachines, due to high reliability, and no interference with parts. Possible applications include medical applications: such as drug dispensing in the body. [5,10]

Vision of "electrical" future. Tesla's prediction include: The widespread use of hydro-electric power generation and of AC for transmission; electrical control of atmospheric moisture (not yet accomplished); use in appliances (refrigeration, etc.), lighting, and propulsion; use in agricultural domain: pest control, elimination of microbes, …; collision-preventing instruments; "*In a time not too distant it will be possible to flash any image formed in thought on a screen and render it visible at any place desired*"; a voice-operated typewriter; picture/text transmission (fax); electric guns and teleautomatic aerial torpedoes (cruise missile?). [2,10]

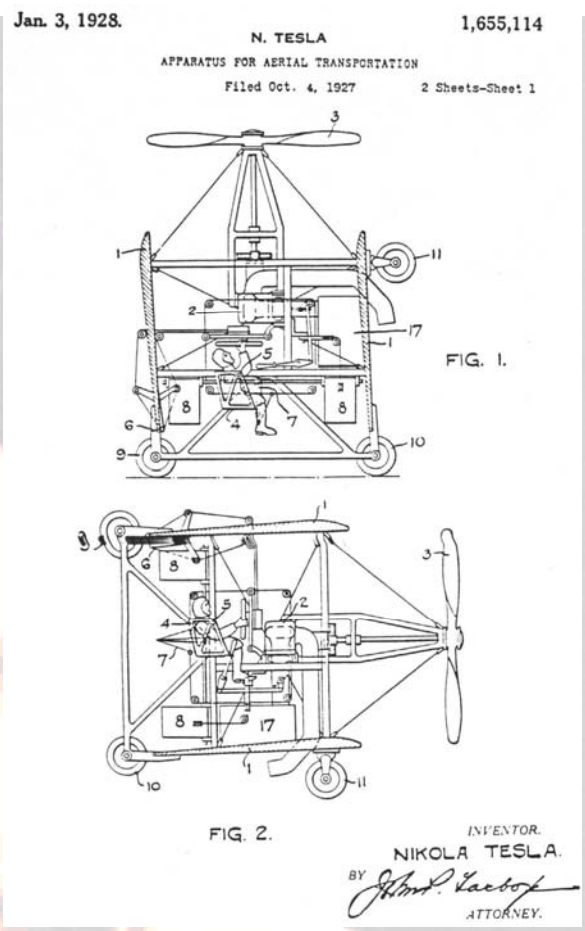


Figure 12. Vertical Takeoff Aircraft Patent

Tesla on Sustainable Energy. [11-14] In his papers on "*The Problem of Increasing Human Energy (With Special Reference to the Harnessing of the Sun's Energy*)" that originally appeared in Century Illustrated Monthly Magazine in June 1900, on "*The Transmission of Electric Energy without Wires,*" that originally appeared in The Electric World and Engineer, in March 5, 1904, and on "*The Wonder World to be Created by Electricity,"* that originally appeared in Manufacturing's Record in September 9, 1915, Tesla presented his visions of sustainable society with affordable energy to be transmitted wirelessly through the earth or air.

"The Sun is the past, the Earth is the present, the Moon is the future. From and incandescent mass we have originated and into frozen mass we shell turn." Amazingly, Tesla pinpoints more than 100 years ago the most important issues of concern to the human race even today: the need for limitless energy, clean water and healthy food.

"This precious fluid, which daily infuses new life into us, is likewise the chief vehicle through which disease and death enter our bodies. It should be made a rigid rule – which might be enforced by law – to boil or to sterilize otherwise the drinking water in every household and public space. " "Millions of individuals die yearly for want of food…. Even in our enlightened communities, and not withstanding the many charitable effort, this is still, in all probability, the chief evil." "In this manner many compounds of nitrogen may be manufactured all over the world, at a small cost, and in any desired amount, and by means of these compounds the soul can be fertilized and its productiveness indefinitely increased. An abundance of cheap and healthful food, not artificial, but such as we are accustomed to, may thus be obtained…"

While talking about the power of the future, Tesla clearly analyses various energy sources know at that time, and points out their advantages and disadvantages:

*"We have at our disposal three main sources of life-sustaining energy – fuel, water-power and the heat from the sun. Engineers often speak of harnessing the tides, but the discouraging truth is that the tidewater over one acre of ground will, on the average, develop only one horse-power… **The force of wind offers much better chances and it is valuable in special instances, but is by far inadequate. Moreover, the tides, waves and winds furnish only periodic and often uncertain power and necessitate the employment of large and expensive storage plants**… If we use fuel (i.e., coal, oil gas - JV) to get our power, we are living on our own capital and exhausting it rapidly. This method is barbarous and wantonly wasteful, and will have to be stopped in the interest of coming generations.*

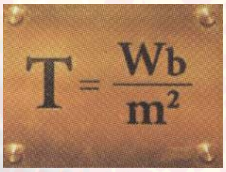
The heat of the sun's rays represents an immense amount of energy vastly in excess of water-power… To do this would mean the installment of apparatus and storage plants so large and expensive that such a project is beyond the pale of practical. The inevitable conclusion is that the water-power is by far our most valuable resource. On this the humanity must build its hopes for the future. With its full development and a perfect system of wireless transmission of energy to any distance man will be able to solve all the problems of material existence. *Distance, which is the chief impediment to human progress, will be completely annihilated in thought, word and action. Humanity will be united, wars will be impossible and peace will reign supreme."*

Tesla considered affordable and abundant energy as the base of peaceful co-existence of human race.

Conclusions

Although Nikola Tesla died alone and poor, on January 7, 1943, his electrifying legacy lives and will continue to live with fulfillment of Tesla's dreams and visionary ideas. The 150th anniversary of Tesla's birth was celebrated all over the World, and the young generations continue to learn about this genius.

In 1956, Tesla's peers at the Electrotechnical Conference in Munich acknowledged his monumental contributions to science by designating his name to represent a unit of magnetic measurement. Thus, the "tesla" (T) became the Unit of Magnetic Flux Density in the SI system. Throughout the entire history of electrical science only fifteen men worldwide have received this honor. [15, 16]



The IEEE, which considers Tesla one of the 12 "apostles" of electrical science, continues to offer an annual prize in the field of power engineering in his name:

"The IEEE Nikola Tesla Award was established in 1975 through agreement between the IEEE Power Engineering Society and the Board of Directors of the Institute of Electrical and Electronics Engineers, Inc. The award consists of a plaque and a cash prize. It maybe awarded each year by the Board of Directors on the recommendation of the Technical Field Awards Council of the Awards Board to an individual, or group of individuals, who have made outstanding contributions to the field of Generation and Utilization of Electric Power. The Award is named in honor of Nikola Tesla, an electrical engineer, a distinguished Yugoslav-American inventor, and a pioneer in many fields, who is most renowned for the development of the coil that bears his name and the a-c induction motor." [16]

Tesla summarized his visions in his lecture "The Art of Teleautomatics" at the Commercial Club in Chicago in 1899:

"Our work, to be the best, must be like that of the planter – for the future! And full of self-denial and nobility of purpose. Its reward, when it final comes, is all the sweeter, because it was long deferred. Selfish instincts and desires hamper every better development in Nature." "The scientific man does not look for a reward. He does not expect his advanced ideas to be readily taken up. His work is like that of a planter. For the future. His duty is to lay the foundation for those who are to come, and point the way!"

The words of E.H. Armstrong, FM Radio Pioneer, emphasize the genius of Tesla: "The world, I think, will wait a long time for Nikola Tesla's equal in achievement and imagination." [2]

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[15] Tesla Memorial Society of New York, http://www.teslasociety.vom/

[16] IEEE Power Engineering Society http://swww2.ieee.org/about/awards/sums/tesla.htm

[17] Most of the pictures in this paper are from Tesla Museum in Belgrade.

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